# THE GAME OF LIFE: TEN PRECEPTS AND A PATTERNED PROCESS

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ABSTRACT. Within the notion of life as a game, the present paper proposes a decalogue of principles and mechanisms that in unison are characteristic features of living organisms. The ten principles are the following: (1) Organized body, (2) Distinctive and symmetrical structure; (3) Autonomous and energetic metabolism; (4) Excitability, sensibility, and response; (5) Modeled reproduction; (6) Homeostatic equilibrium; (7) Growth and transformation; (8) Synchronized rhythms; (9) Autonomous preservation, and (10) Patterned behavior. Each principle is briefly defined in an attempt to show its absolute relevance to the resulting phenomenon recognized as life. The principles are regarded as necessary but insufficient to explain life since there are global life properties emerging from their interaction and integration. A theory of patterned processes considered as emergent, complex, and kinetic properties of live systems is advanced. The theory is thought to provide a language appropriate to describe both the structure and the activity of every biosystem.

KEY WORDS. Definition of life, game theory of life, life forms, metabolism, homeostasis, homeorrhesis, reostasis, autopoiesis, excitability, behavior, patterned process.

*Resembles Life what once was held of Light,*
*Too ample in itself for human sight?*
*An absolute Self—an element ungrounded—*
*All that we see, all colours of all shade*
*By encroach of darkness made?—*
*Is very life by consciousness unbounded?*
*And all the thoughts, pains, joys of mortal breath,*
*A war-embrace of wrestling Life and Death?*
*S.T. Coleridge*

## *LUDUS VITALIS*: THE GAME OF LIFE

If biology is the study of life, it would seem of supreme importance for this robust discipline to offer a complete and precise definition of life. However, as we know from past setbacks and present obstacles, such precision is by no means easy. Nevertheless, instead of being embarrassed by this apparent deficiency that characterizes the subject of her specialty and

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talent, the biologist can in fact smile in the knowledge that she is in excellent company, as it is equally difficult for other scientists to offer concrete definitions of their central issues of concern and analysis. For example, as is the case with life, matter and energy resist a simple characterization in the physical sciences. Neither is culture a crystal-clear concept for anthropologists, nor illness for doctors nor the mind and behavior for psychologists. Science suffers from a nominal paradox: it seems that an accessible and lucid definition of the general object of its disciplines mockingly withdraws while the boundaries of the respective sciences advance, although these concepts must be all sufficiently clear to have provided material for centuries of inquiry, discovery, and comprehension.

Many scientists consider a waste of time to torture language and logic to provide a simple formula for their object of study, which is far from simple and seems to challenge common sense itself. For these scientists, it is more than enough to share themes, methods, and approximations of a concrete reality well demarcated by the historical practice of their disciplines. After all, reason these researchers, it is not very clear what good might have come out of a discussion as famous as the one that took place between mechanicists and vitalists regarding the concept of life around the 1920s. The two-time Nobel laureate, Linus Pauling (1938), insightfully observed that when it came to life, it was easier to study it than to define it. No doubt, this pragmatic attitude is acceptable enough for our good scientist to forget about concrete definitions of her general subject of study, and to proceed with analyzing the particular problems that are sufficiently well demarcated to allow her to conceive hypotheses and projects about them, uncover facts and formulate models as dictated by her abilities and the current methods. However, it is undeniably strange that we lack concrete definitions of central scientific concepts, as if biology had declared itself incapable of extracting general principles from its enormous accumulation of empirical data to establish a solid definition of life.

In the Seminar on Scientific and Philosophical Problems at the Universidad Autónoma de México, during a vigorous term of discussion and analysis prompted by a lecture by Mario Casanueva, the challenge to define life was posed for those participants closest to the biological disciplines. What follows here is a development of the contribution I made to this discussion on Thursday, November 25, 2004, in which four prominent researchers in the field of basic biomedicine in Mexico participated with their own solutions: Marcelino Cereijido, Eugenio Frixione, Ruy Pérez Tamayo and Ricardo Tapia. From the conceptual framework presented in my initial lecture, and from the subsequent debate and its later development and translation, this manuscript has arisen, which I have been so bold as to send to *Ludus Vitalis*, because in attempting a definition of life I have been compelled to play with a range of propositions, and because the *game of life* is in fact the translation of this distinguished journal name. Indeed, as will be shown in this work, contemplating life reinforces not only the dynamic nature of vital processes, but the view that these processes constitute a scene of dramatic and decisive conflict; i.e., a game of life or death. This *game of life* does not have the connotation of enjoyment or entertainment here, but defines that activity in which those who take part in the regulated action make a methodical effort to achieve their own objectives as opposed to others. Thus, rather than defining life, as the dictionaries do, as a necessarily mysterious faculty to perform certain acts, it may be more useful to define those processes that characterize it, and to suggest how they come together to make up that which, unlike the slippery and largely evasive concept of "life," is palpable and clear; I refer here of course to the *living organism*. In this proposal, we will examine the idea that the vital processes of organisms are not only dynamic and patterned, but that they exhibit an energetic course of conflict which is inherent to them: without alternative, urgency, motion, collision, and contention, life would not be possible at all. One way to express this is to say that life is not an almost inconceivable noun, but a verb: the verb "to live." In other words, more than attempting to define a probably ungraspable faculty or property, we will begin by elucidating the processes of all living beings, or more precisely, the processes of being and staying alive, of being in the process of living.

According to the now classic theory of games, by von Newmann and Morgenstern (1947), to understand a given game and the strategies used by the rival agents, a complete description of the rules is required. In other words, if we propose that life is a game, we are obliged to specify the rules and strategies that regulate it. The game theory has been applied in evolutionary biology by Maynard Smith and his collaborators since 1982, in such a way that species or genes are defined as the players. In this case, the tactics of the evolutionary game are not deployed by rational agents but by elements endowed with possible strategies, and success is not measured by an expected utility, but by the number of copies that the strategy yields to the organism that employs it. More recently, the concept of the *game of life* has also been used to refer to self-replicating patterns whose organization emerges from simpler interactions of elements, capable of being programmed in one of the algorithms constituting what is known as *Artificial Life*. In this work, I will not refer to these fascinating mathematical exercises beyond pointing out that life patterns are the result of more elemental functions or forms of organization and that it is therefore necessary to identify such functions before being able to embark on an analysis of their results.

Gerald Joyce (2004) of the Scripps Institute has defined life for NASA as "a self-sustained chemical system capable of Darwinian evolution." However, this definition does not take into account that many life forms are not self-sufficient and need, for example, microorganisms to continue living. Furthermore, the concept of Darwinian evolution does not lend itself to an accurate evaluation of an existing organism, as there is no direct proof of a process that takes thousands or millions of years. It would not be possible with this definition to confirm the life of an organism, although it would be certainly possible to determine whether the organism has a reproductive capacity or a metabolism, two necessary vital functions.

It is thus particularly significant that life has not been successfully defined as a general, abstract or independent property or faculty, but rather in terms of highly tangible and evident properties which, in light of biological data, exhibit certain complex, multiple and diverse systems called organisms, creatures, individuals or living beings. In the words of the notable Mexican physiologist Hugo Aréchiga (1999): "Life is a complex function of vast collections of molecules, integrated into a higher level of organization, which we know as the individual or living being." Note that Aréchiga astutely avoids saying that the higher level is "life", and opts instead for "living being". Therefore, before attempting to define life as a faculty, it would be helpful to stipulate first what characterizes a living organism, i.e., to determine the rules and strategies that the agent, individual or living organism uses in the contention for survival and fertility, which collectively amount to victory in the game. In other words: if we concede that a satisfactory definition of life should take the form of a general theory of biosystems, we must define the properties that shape it and use them to search their bonds and connections that produce that resultant we call life.

## THE DECALOGUE OF LIFE

Below I propose and describe ten properties as salient and particular characteristics of living organisms and which necessarily cease or disperse at death. This "Decalogue of Life", which I will comment on and explain presently, runs as follows:

1. Organized body
2. Distinctive and symmetrical structure
3. Autonomous and energetic metabolism
4. Excitability, sensibility, and response
5. Modeled reproduction
6. Homeostatic equilibrium
7. Growth and transformation
8. Synchronized rhythms
9. Autonomous preservation
10. Patterned behavior

## 1. ORGANIZED BODY

Every living organism consists of a body constructed from various elements organized into a single mass. It is not only an intricate and admirable three-dimensional sculpture that challenges gravity and entropy, but the complete material of an individual, which is exquisitely designed to constitute a collection of articulated elements that result in an overall uniqueness. A living body is a specially organized and hierarchical system, coordinated and explicable at diverse levels of structure and function, whose *period of life* comprises the duration of its operations somewhere between fertilization and death.

Although the elements that make up a living organism on Earth are quite limited, particularly carbon, hydrogen, oxygen, and nitrogen, the traditional CHON compound, to which should be added phosphorous, as it is essential in the necessary energy exchanges (i.e., the CHONP compound), it is necessary to consider various levels of organization in every living being. The organic levels defined by the articulated structure of its elements are the following: atoms, molecules, cells, tissues, organs, systems, organisms, and socio-ecological systems. These eight levels of composition usually entail increasing distinctions of ethical value. According to the cellular theory promulgated by Theodor Schwann (1810-1882) around 1847, the threshold at which to consider a system as living is in fact the cellular level, although the boundaries are somewhat blurred: the organelles of the cell or viruses can be classified as operators of the living cell and, although they exhibit certain vital properties, they do not coordinate all of them. Furthermore, the living body is more than something definable by its composition, as its formative elements are replaced periodically.

It is sometimes argued that the basic components of living organisms do not necessarily constitute the elementary building blocks of every living being. It is possible, for example, to conceive living organisms made of silicium instead of carbon. In the same vein, it seems feasible that water, which forms the larger part of all living beings and is indispensable to their continued existence, would not be necessary to define life. However, this exclusion should be reconsidered. If life as we know it necessarily requires that the living body has water; if water is indispensable for its creation, occurrence and endurance, if at least two thirds of a living body is water, it seems inevitable to conclude that water necessary to life and to understand why this is so. Actually, water possesses unique properties which are required for life and plays many truly vital roles in every organism (Chaplin 2001). For example, the properties of water as a universal solvent, its osmotic qualities and its capillarity, are indispensable factors to the occurrence of vital functions. Indeed, water is the soluble medium of all bio-molecular interaction, the distributor of nutrients, hormones and every metabolite within and between cells, the medium for the elimination of wastes and toxins, the necessary reactive or product for numerous metabolic reactions, the thermo-regulator and lubricant *par excellence*, and the essence of the cytoplasmic gel. Without the uniting force of hydrogen in water, DNA helices would not be able to join together or separate, enzymes would not acquire their three-dimensional structure or their flexibility, and membranes would not exhibit their required permeability.

Although it is possible to imagine living organisms outside Earth whose structure is based on other elements, a preferred theme of science fiction, it is impossible to conceive of a living system on our planet that does not require water and that results in a water-based body. Of course, there are molecules far more unique or exclusive to living systems than water, such as proteins and nucleic acids. In fact, even though it could well be said that living systems produce and use these polymers by and for themselves, it must be added that the stratified and total organization of the molecular sculpture and its functions define a living organism more than its composition.

A living body is a particular structure that tends to dissipate at death, and that is the subject of study in a group of disciplines within biology known as the morphological sciences, which include anatomy and histology.

## 2. DISTINCTIVE AND SYMMETRICAL STRUCTURE

The body of the living organism is not limited to its material composition and organization, as there is a typical form for each *species* which is uniquely individualized for each organism or, to use the classical nomenclature of biology, for each *specimen*. Such body form was the distinguishing feature for the formal classification of the living organisms through the collection of specimens and the comparison of similarities and differences with the forms of the known species. Indeed, as has been repeatedly accepted since Carl von Linné (1707-1778), the basic taxonomic unit in biology is the species, that is, the grouping of living beings that exhibit two associated properties: common anatomic, physiological and morphological features and the possibility of reproduction confined to its members.

Although it is perceived as something unified and whole, the physical form is far from a simple category, as every living organism has a unique topography, a refined physiognomy and a laminar geometry ordered at all its levels of organization and analysis, from the molecular structure to the configuration of the organism as a whole. This configuration constitutes a temporary pattern whose form is preserved in spite of the rapid replacement of its elements; in other words, the distinctive structure of the organism is a patterned process. Unlike elaborate sedentary formations such as many inorganic crystals, or vibrant productions such as the flames of fire, living organisms have a *refined structure*, intricate, stratified, and harmonious. The notion of a 'refined structure' refers to the fact that the living organism exhibits an ordered arrangement or configuration not only at macroscopic level, but also at microscopic and ultramicroscopic levels.

The topology of the body can be considered as the architecture resulting from a design plan, called "*Bauplan*" in German biology (Troll, 1935). It is a basic organization plan consisting of a set of specific data for a species that determines the arrangement of its growth, the relationship of the organs, and finally its adult form. The consistency in the form of the species is thus associated with a basic structural design, a kind of prototype or archetype of the species. Because of its evolutionary design, the form of the organism is functionally consistent and mechanically effective because it is functionally immersed in that network of causes and crossed signs that is conceived of as the environmental niche, with which it establishes a dialogical unity, that is, a game of give and take. This form evolves in living beings to adapt to the demands of the niche in such a way that very distant species develop similar forms, like the fins of ichthyosauri, of fish or of whales which, independently of their huge phylogenic distances, are adapted to the restrictions of their aquatic environment and acquire similar forms, appearances, and functions.

A most salient and common feature of the physical form of living creatures is its symmetry. The symmetry of the living body can be considered as the result of dividing it into two lateral parts with an imaginary plane positioned at right angles to the horizontal surface of the Earth. This fact provides moving organisms with a facility for traveling over that surface, particularly in a forward direction. Stationary organic beings, such as plants, fungi, and certain coelentera, do not require this symmetrical axis, although they nevertheless exhibit a radial symmetry.

With regard to physiognomy, it is interesting to observe that all living individuals are different from one another, not only those of the same species, but even siblings and, in their details, even monozygotic twins. The individual physiognomic identity is complemented by numerous identification and recognition mechanisms. Indeed, identification exists from the cellular level, at which the immunity mechanisms are constituted, to the organism as a whole, which, in the case of human beings, amounts to the distinguishing features of a person.

### 3. AUTONOMOUS AND ENERGETIC METABOLISM

All living organisms exchange energy with their environment in an active and sufficiently effective way, as they are capable of maintaining their stability through increasing the entropy of their niche and thereby by restricting their own. Indeed, as has been confirmed since the classic essay by physicist Edwin Schrödinger (1967), living organisms are actually islands of order, negative entropy, or *negentropy*. While considering living organisms from this perspective, we seem to witness two "arrows of time" one pointing towards entropy and disorder and the other, that of living systems, aimed in the opposite direction, i.e., towards the construction of systems of growing order. Living organisms are therefore open systems situated far from equilibrium and subject to the control of the sun's energy. Just as the celebrated Parisian chemist Antoine Lavoisier (1743-1794) explained, it could be said that the fire stolen from heaven in Prometheus' torch is a fitting metaphor for understanding the operations of combustion in living beings.

Life depends totally on energy and is characterized by making autonomous use of it. Metabolism is the process by which a living organism acquires and utilizes energy to carry out its diverse functions. The organism exhibits intricate faculties for incorporating, storing, processing, converting, extracting, and utilizing energy from chemical substances such as respiration, digestion, and biosynthesis. The metabolic process couples the exergonic reactions of oxidation with the endergonic processes that maintain vital functions, such as mechanical operations, transport and biosynthesis of molecules. The energy of the biosystems is captured and diffused in an efficient, gradual, and highly controlled manner in the *biosynthesis* of molecules, cellular components, tissue and systems, i.e., in the processes known collectively as *anabolism*. At the same time, all these components are subject to mechanisms of replacement, dissipation, and degradation which constitute the processes of *catabolism*.

Anabolism and catabolism are antithetical processes which nevertheless need to operate together for the subsistence of the organism intimately linked through an energy coupling. Thus, for growth to occur, anabolic processes of assimilation and molecular construction and catabolic processes to release the necessary energy in biochemical reactions are required. Adenosine triphosphate (ATP) is the currency of exchange in the cellular economy as it transfers energy stored in its chemical compounds to the reactions necessary for anabolism. In short, catabolism generates ATP, anabolism requires it, and all life forms are in critical need of this molecule. The balance is highly malleable, so much so that the predominance of anabolism results in growth and that of catabolism in loss of biomass. In the words of Hugo Aréchiga (1999), life requires an intricate process of molecular traffic inside, outside, and between cells.

It seems extremely significant in the game of life that the biochemical mechanisms for transforming nutrients into energy are similar or, to a considerable extent, identical in all living organisms. In all cases photons are used as the original energy source, molecular oxygen ($O_2$) as a prerequisite, water as a product, ATP to store and provide the energy, enzymes as catalysts, or glycolysis as a release mechanism. As opposed to fire, in which autonomous molecular conversion also occurs, releasing all the energy of its fuel in the form of heat, the chief characteristic of the vital metabolism is the molecular assimilation in successive stages, which, by the way, implies an uncertain demarcation between substance belonging to and distinct from the organism.

### 4. EXCITABILITY, SENSIBILITY, AND RESPONSE

Every living organism generates electric fields in such a way that electrochemical excitation and conduction are universal properties of living beings. The basis of biological excitability is the exquisite sensibility of the cellular membrane to chemical changes in its environment. Bioelectricity was discovered by Luigi Galvani (1737-1798) around 1780 by causing a muscle contraction in the leg of a frog through the electric stimulation of the nerve. It is now known that every bioelectrical phenomenon always involves processes of transportation of ions through the cellular membrane. It is a form of energy stored in the form of electrochemical potentials that can be converted into other forms of energy such as photosynthesis, transportation of metabolites, mechanical operations, muscle motion, and signaling processes. The membrane spreads waves of excitation by means of electric impulses that are generated by changes in the concentration of ions. The distribution of ions and other molecules is determined by transportation mechanisms associated with the structure of the plasmatic membrane and the depolarization results from the passage of electrically charged ions through it. This mechanism is universal for all cells and constitutes the biological basis for the transmission of information inside and between cells.

The capacities for processing information involve two basic properties of the living organism, *excitability* and *sensibility*, capacities to be activated by stimuli (energy variations in the environment that hit specialized receptors) and which respond to them in the form of internal activity in the case of excitability, and external in the case of sensitivity. The mechanisms for processing information involve the transduction, interpretation, and execution of *signals* that are similar or the same in all living organisms endowed with facilities and capacities for processing information. In the case of nervous tissues, the information is dispatched according to the frequency and temporal pattern of the action potentials.

The most elemental form of nervous response to a stimulus consists in what is called the "reflex arc", which is released by a stimulus that activates a neuron so that it in turn stimulates another motor neuron, which produces a motion. As we know from the classic research of Ivan Pavlov (1849-1936), a large proportion of the functions of living organisms conform to increasingly developed *reflexes*. At their highest level of development, these capacities for processing information become mental apparatuses, i.e., representations of the internal and external reality of the organism which enable a response that is no longer automatic, but intelligent and deliberate to the environment. In short, life is not only sensitive, but expressive as well.

Whether inside each cell or unicellular organism, between several cells and tissues, between organs and systems, between the organism and its niche or between diverse organisms through chemical or physical and eventually semantic messages, life always involves communication processes. As we know since Herbert Spencer (1820-1903), every living organism adjusts its operating conditions to those of its environment or niche. The relationship of the information received and sent between the organism and its environment is mediated by the organism's internal transformations which promote its own subsistence.

## 5. MODELED REPRODUCTION

Every living organism perpetuates and replicates itself because it contains a codified description of itself. It is not easy to imagine a non-living structure containing such a description of itself, and this appears to be another definitive feature of life. The facts uncovered by modern molecular biology constitute the peak and elucidation of various basic biological laws which were discovered and formulated in the middle of the nineteenth century by four revered European biologists who were born within a few years of each other. These laws are the following: (1) Every cell comes from a cell (Rudolf Virchow 1821-1902); (2) every living being arises from another similar living being (Louis Pasteur 1822-1895); (3) each one of the hereditary traits is transmitted independently of the others (Gregor Mendel 1822-1884); (4) adaptations exist over wide margins of time and the selection of adaptable mutations eventually generates new species of living organisms (Charles Darwin 1809-1882). These laws imply that all life on Earth must be derived from a primordial cell and provide a way out of the chicken-or-the-egg paradox, as genetic material is not transformed during the life of the animal. The first chicken in the course of evolution must have existed first as an embryo inside an egg, although due to mutations the egg was not laid by a chicken. The possibility that the chicken existed first is implausible.

The capacities of continuity and reproduction of the living organism are founded on a genetic code or genotype which is duplicated, transcribed, and expressed as a phenotype, i.e., as the elements of its own structure and operation. It seems highly significant to note that the molecular mechanisms of genetic realization (DNA-RNA-protein) are similar or virtually the same in all living organisms of the planet. In his famous book

*What is Life?* the physicist Erwin Schrödinger (1967) underlined the fact that in inorganic systems a high number of molecules are required to produce a given effect, whereas in living systems a relatively small number of molecules of the genotype govern the structure and function of a whole organism, something that he considered exclusive to living matter. Francis Crick (1981) has suggested that a basic prerequisite for life consists in systems capable of replicating their own instructions and all the machinery needed to execute them.

The reproduction of living beings occurs through two highly distinct strategies: asexual, which is relatively rare and confined to some undeveloped organisms, and sexual, through genetic exchange between two individuals of distinct characteristics, one female and the other male. Sex constitutes a highly marked characteristic of living organisms, and its manifestations include physiognomy, identity, and behavior. As we all have experienced, even motivation and social role are affected by sex, and we conceive such roles as gender.

While discussing the reproductive capacity as a characteristic of life, it is necessary to make the qualification, not obviously less significant, that an organism does not produce exact replicas of itself, but rather modified copies. Differentiated offspring refers to the production of similar but not identical copies of the original organisms, which is the condition necessary to evolution, as the variations in the progeny establish differences in their possibilities of adaptation, subsistence, and reproduction.

## 6. HOMEOSTATIC EQUILIBRIUM

Every living organism exhibits a regulated maintenance of relatively stable constants in its internal environment or *milieu interior* as occurs, for example, in the case of its percentage of water or sugar and salt contents in the blood. The *milieu interior*, a revolutionary concept of Claude Bernard (1813-1878), is space of exchange, a crossroad where the activity of different systems is regulated. The composition, structure and balance of the *milieu interior* depend on the cellular activity and metabolism and in turn the functioning of the cells depends on its integrity. This balance is made manifest in the so-called health of the organism.

In his classic book, *The Wisdom of the Body,* from 1932, Walter Cannon suggested the concept of *homeostasis* to refer to the constancy of the internal environment. Homeostasis can now be considered as the regulated maintenance of reference levels in an area of tolerable equilibrium, and is made up of control networks, usually of negative or positive *feedback*. These control mechanisms operate at all levels of an organism and integrate all the tissues to maintain their overall condition within a relatively narrow range of operations, close to the optimum through servomechanisms known as *feedback circuits*. The full set of these controls allows the organism to subsist in variable environmental conditions through internal control mechanisms initially proposed by N. Wiener and A. Rosenblueth (Wiener 1948) under the name of cybernetics. In short, every living organism is a homeostatic system in the sense that it is maintained relatively stable because its functional internal organization is dedicated, as a whole, to maintain that order.

From the earliest eras of human history and in through its diverse historical manifestations, the concept of health in the diverse medicines has supposed a state of balance in the individual, as much with reference to the equilibrium of internal functions as to functions related to the external environment. Several of the functional constants, such as arterial tension, cardiac frequency, respiratory frequency or temperature, constitute those signs of life that in medicine are called *vital signs*, a concept both useful for and definitive to the vital processes in multi-cellular organisms endowed with cardio-respiratory systems, and whose ceasing is the traditional sign of the death of the organism.

Homeostasis and the regulatory processes of variables within a relatively stable range are characteristic not only of living beings at their intracellular, intercellular and organic levels of operation, but also expanding up to the level of the ecosystems, in which the food chains and predators are maintained within ranges that allow the survival and evolution of the whole niche. Some have suggested that this niche covers nothing less than the entire terrestrial surface where life progresses, i.e., the whole biosphere. I refer, of course, to the well-known Gaia Hypothesis put forward by Lovelock and Margulis (Lovelock 1990).

## **7**. GROWTH AND TRANSFORMATION

Every living organism exhibits not only mechanisms for maintaining its functions relatively constant, just as we have defined for homeostasis, but also defined trajectories for acquiring new elements, states, and points of operation usually through *feed-forward* mechanisms projected towards an objective. Such directed trajectories, or *chreods*, are true pathways of metamorphosis, as is the case with growth and development, meiosis, embryogenesis, morphogenesis, lactation, hibernation, learning, or cerebral plasticity. Not to mention the more spectacular metamorphoses of certain species of insects and frogs or toads which occur after their birth or hatching that can become complete variants not only in form but also in physiology and metabolism. Thus, unlike homeostasis, which maintains the points of operation relatively constant, trajectories of transformation constitute what is called *homeorrhesis* (Waddington 1957) by integrating themselves through an interaction between the genetic program and environmental restrictions, i.e., through an epigenetic interaction. The culmination of a development stage is characterized by the assimilation of certain characteristics that enable the organism to embark on a new stage of transformation.

A particularly significant consequence of development and growth in multi-cellular beings is the production of specialized cells, i.e., of cellular stock notably different in appearance and functions from those from which they originated and which, grouped in diverse ways, constitute tissues and organs capable of carrying out particular biological functions as diverse as digestion, intelligence, or reproduction. The disruption of the order in differentiation can result in serious pathologies such as cancer. From the totipotential ovum to each differentiated cell of the adult organism, the long trajectory is marked by an intense interaction between the genome and the niche or local molecular environment that can vary in such a way that the cells acquire certain characteristics and not others. For this reason, independently of their appearance and functional specialty, all the cells of an individual contain the same genetic endowment.

Thus, as a result of the differentiation of cellular stock, every living organism passes through a sequence of notable although gradual transformations until it reaches its adult stage. These are the stages of development and growth, maturation and differentiation, subject to a modeling that conforms to a program of interaction between the genetic script and its interpretation in a variable molecular environment and a particular environmental niche. It is in this way that multiple cells or tissues that have the same genetic endowment can differ widely in their phenotypical traits of expression in the event that their environment or niche is different.

At a certain point in its life cycle, and in contrast to constructive acquisition, the organism also exhibits trajectories of damage and deterioration that inexorably lead to its extinction. Since the stages of development are repeated in each generation, a *life cycle* occurs between two equal stages in the following generations. The cycle is similar or the same in all multicellular organisms as in normal conditions they all gestate, are born, grow, mature, reproduce, age and die.

## 8. SYNCHRONIZED RHYTHMS

Every living organism maintains a periodic organization of rhythmic and recurrent functions through the operation of biological clocks. Biological processes occur subject to variations in their duration, usually periodic in nature, which are adapted to a sinusoidal function. Such cyclical variations reveal the simple fact that an organism must adapt to the changing environment of our planet, moving itself in rotation and translation with reference to the sun.

*Biological rhythms* are a characteristic of all living organisms and operate at all levels of organization, in such a way that we can encounter rhythms within rhythms within rhythms. The surviving organisms have through the generations developed adaptations to various environmental cycles, such as light, tides, lunar phases or seasons and with such development come switch systems, which allow internal coupling with the geophysical period. Over time the oscillator is internalized and becomes a *biological clock*, which is in fact an endogenous and self-sustained oscillator. The most frequent biological rhythms are those close to the Earth day of twenty four hours, i.e., *circadian rhythms*. In these rhythms the clocks are synchronized with a light sensor called a photoreceptor, which responds to solar light.

Thus, unlike homeostasis, which controls biological variables to a point of adjustment, or homeorrhesis, which controls them to an established trajectory, *reostasis* denotes an oscillatory control over the biochemical, physiological, and behavioral values of the living organism. The components of a reostasis are coordinated internally not only through negative *feed-back* mechanisms or *feed-forward* mechanisms, but, particularly, through lateral adjustment mechanisms (*feed-sidewards*) by mean of a network of spontaneous and reactive rhythms, but mutually modulated and synchronized. We are really talking about modulations programmed among the multiple rhythms of a biosystem. The neuro-endocrine system of vertebrates is an excellent example of this enormously intricate coordination.

## 9. AUTONOMOUS PRESERVATION

Every living organism is an autonomous system in the sense that its most characteristic process is the continual production and generation of itself. Living organisms exhibit the paradox of being open systems in the sense that they exchange with the environment material, energy and information, and, at the same, time closed systems due to the fact that they maintain their identity through internal and autonomous processes that reproduce their own components. Indeed, every living organism develops its parameters of organization autonomously and automatically, i.e., it is a system of *autopoiesis.* Following the original idea of Varela, Maturana and Uribe (1974), an autopoietic system is *self-contained*, *self-generated*, *self-repairing,* and *self-perpetuating*. This vital principle has been complementarily explained as a dissipative structure by Prigogine and Nicolis (1977) and as cognitive systems by Bateson (1973). Autopoiesis therefore designates the form in which systems preserve their identity through internal operations that reproduce their own components. In other words, systems exhibiting a network of processes and operations that can create or destroy elements of the same system are autopoietic. In this way, although the system changes structurally, the network continues during its existence, maintaining its identity. In such fashion, an autopietic system can be understood in contrast to allopoietic system that uses raw materials to generate a product through means other than itself, as it occurs with factories. An autopietic system would be like a factory that uses raw materials to maintain and produce the very same factory that, in turn, is capable of acquiring and giving rise to its own components and the processes to build itself.

Autopoiesis is not exclusive to living beings. It is a feature also exhibited by social organizations, which are capable of organizing themselves even in dangerous situations. Nevertheless, unlike these and other systems, living beings are *molecular* organisms capable of self-generation, biochemical factories that work according to internal rules to reproduce their own configuration. The basic idea is that living systems are structurally determined: what occurs within them occurs as part of their structural process and is determined by it. Autopoiesis is an innovative and creative process (Maturana and Varela 1990).

## 10. PATTERNED BEHAVIOR

Every living organism spreads out in time as the dynamic path of its forms, i.e., as kinetic transitions of internal and external states in close interaction with the environmental niche. This transformation of motions, acts, or behavior in living organisms appears in many intricate and unpredictable variations.

Behavior is one of the phenomena characteristic of all living beings, although it is much slower and limited in plants. From the unicellular individual to every multi-cellular organism, the patterns of physical action are typical of every biosystem. In complex organisms, they constitute physical forms in motion, which establish a spatial execution of the segments of their body dependent on time. The patterns of elemental actions integrate particular and typical spatio-temporal processes, which are referred to as *behavioral units*. Every species has a set of behavioral units and non-patterned movements that serve as adaptable pieces of execution and communication. These movements and units of behavior are endowed with a certain amplitude, duration and muscle tone, which enables them as real units of information in close relation with and demarcation by environmental factors such as the force of gravity and the spatial characteristics and restrictions in which the individual moves.

The motor events of living organisms are processes that can be recognized as patterned in the sense that they constitute transitions between particular configurations. Thus, a segment of behavior consists of one or several superimposed series of behavioral units and movements which exhibit certain sequences, cadences, combinations and expressive qualities. The temporal ordering of behavior is typically stochastic, i.e., it is neither totally ordered nor totally random. This is characteristic not only of the sequences of spontaneous behavior in elemental, animal or human organisms, but in patterned series of communication as complex as music and language.

When several individuals live together in the same group and space, the exchange of behavioral units among them constitutes interactions of communication that in time define their relationships with one another. The set of relationships constitutes the social structure of a group of individuals of the same species in which particular social properties emerge, such as the hierarchy of dominance. Finally, the development of social structure over time is what shapes history (Díaz 1985).

## GLOBAL LIFE PROPERTIES

One of the problems with listing vital properties, such as the Decalogue outlined above, is that there exist different processes and systems that place them in doubt. There are the systems that we do not consider living but that conform to several of the listed properties of living beings. The best example is fire which grows, moves, displays metabolism, responds to environmental stimuli, and consumes and excretes matter and energy. The crystals in certain solutions also grow and reproduce. Secondly, there are systems that we consider living but that do not exhibit several of the processes listed. The classic example is the stubborn mule that does not reproduce or participate in Darwinian evolution but that undoubtedly is alive. Also, many seeds can remain dormant for decades or even centuries without changing, moving or growing, without metabolism or reproduction, but we do not doubt the fact they are living. Viruses, as we have seen, satisfy several of the requirements but not all. We might therefore consider them cellular parasites on the fringes of life. Nevertheless, after considering these counter-examples, we can still assert that living organisms are only those that actually or potentially bring together all the enumerated characteristics.

The mere enumeration of the basic characteristics of living beings, however complete, will not produce, on its own, a satisfactory definition of life, as life is not a simple sum of these parts and operations. We must come to understand how these functions conjoin to produce the more distinctive result that we do not understand well. In other words, these ten principles or vital properties, although separately identifiable, do not constitute independent traits in themselves; quite to the contrary, depending on their connections, cooperation, and synthesis they shape the single property we call and recognize as life, whose unity or functional network is extremely difficult to comprehend due to the unusually high level of its complexity. This is probably the main reason that life is not definable or understandable in a simple or concrete concept.

Indeed, if each one of the vital properties can already be conceived to arise as the result of numerous and intricate constitutive and functional mechanisms, their final synthesis acquires huge proportions of complication and difficulty for our understanding. Consequently, life as a global property continues to have a distinct quality that seems to lie far beyond that of mechanism and the automaton. A challenge for theoretical and empirical biology will be to articulate notions in plausible models that encapsulate the resultant or integral properties of the life process. Perhaps it would be possible to postulate that such a kinetic, autonomous and functional unit of life, which can already be envisaged, would correspond to certain vitalist notions of the past, such as Bergson's *élan vital*, the vital force, the life breath, or other equivalents. Thus, the age-old controversy between *mechanicism* and *vitalism* could reach a new conceptual stage without recurring to notions outside biology itself, although, as we have seen for each of the properties enumerated, it will be necessary to include crucial factors of the niche or environment as part of the model. More precisely put, it is in the interchange, in this game between the organism and the environment where one of the global properties of life is to be found.

The global properties of living organisms has of course been postulated since von Bertalanffy's (1976) general system theory as an *emergence,* and this concept continues to present, in spite of its difficulties, a heuristic possibility for the comprehension of life. Indeed, every living organism exhibits integral properties that can be conceived as *emergent* as they constitute resultants of coordination of elementary functions. Theoretically, these resultant properties should be *deducible* from underlying morpho-physiological operations but not *reducible* to them. However, to simply say that life is an emergent property of the assembled parts of organisms would nevertheless be inconsistent with a fuller understanding of life, unless we are able to specify the precise nature of the emergent phenomenon. In the event of not achieving this, the notion of emergence by itself will take us back to the beginning of the discussion.

To avoid such tedious tautology, it would perhaps be convenient and useful to point out at least four properties, which are general or integral to the definition of life that we have just outlined: homeostasis, homeorrhesis, reostasis, and autopoiesis. The goal of an emergent theory of life would consist in specifically and consistently establishing the interactions and eventual integration between those properties that determine an understandable and appreciable global resultant. At present there are no models that attempt to integrate these complex and even antithetical vital functions. The current approach of artificial life, by which resultant virtual properties are obtained from constituents or rules which are simple and well-defined in algorithms, constitutes an important model of study due to its diverse implications and promising applications. However, it is still not known whether this approach will eventually lead to a better comprehension of the emergent properties of living matter.

Perhaps one of the conclusions that might be drawn from the ten principles or vital functions is that life is not a property of matter, but of form. This Aristotelian dichotomy cannot be taken too far, as there is no form without matter to support it, but without doubt the forms in action or patterns that characterize the vital processes will be able to be better understood in terms of principles of patterns in motion or patterned processes, as we will see shortly. Another global property that emerges from the sum and interaction of the ten principles outlined above is that life involves a dramatic contest full of paradoxes. The struggle and challenge of living organisms is evident in each one of the ten principles mentioned, as they highlight a constructive aspect, they are nevertheless based on obvious antagonisms, such as those defined by anabolism and catabolism, mitosis and apoptosis, order and chance, configuration and replacement, balance and imbalance. Life seems to develop on the vertex of such two precipices since an absolute order would be as sterile as the apparent chaos of disorganization. Paraphrasing the theory of games, it could be said that vital phenomena unfold in the context of a conflict between the organism and its environment, and between various organisms, or between various biological systems, from cellular groups to groups of individuals whose adaptation mechanisms are antagonistic. Biological organisms and their multiple parts bring into play diverse adaptation strategies that are not always successful.

Although some two hundred years ago Xavier Bichat (1771-1802) astutely defined life as the set of functions that are opposed to death (Aréchiga 1999), this definition is a logical trap as it in fact obliges us to define the set of vital functions that constitute the reverse of death, and death as the permanent ceasing of the vital phenomena of an organism, whether the necrosis of a cell or the death of an individual. This is another circular tautology that provides no real understanding of either one or the other concept beyond a preliminary intuition that understands life as opposed to death and a living organism as any system entity that dies. Again, the problem with such an apparently obvious characterization of life is that death is by no means easier to define than life. The most dramatic and excruciating paradox of life for those who contemplate it is the following: while everything seems to indicate that life is designed to be perpetuated, individual organisms ultimately fail in their objective to subsist and, whether by ageing, pathology, inexperience, or accident, they all eventually die. However, it must be said that although the individual organism does not survive, on dying it successfully perpetuates both the vital capacity and the general form of the species through successor organisms. In the fortunate concept of Blank-Cereijido and Cereijido (1997), life not only involves death, but truly requires it.

One of the chief characteristics of complex systems is the dynamic behavior of the forms or configurations that constitute them (Mainzer 1994; Yates 1982). We could derive from the theory of complex systems that every living system exhibits two interconnected characteristics: a holistic and hierarchic dynamic of multiple levels, each level composed of multiple parts, and a coordinated interaction between parts and levels. The unification of these two characteristics gives as a result a non-linear stochastic behavior defined by the development of dynamic patterns that we can recognize as spatio-temporal patterns of vital activity (Díaz 1997). From this point of view, the living organism is effectively a dynamic system defined by a patterned process of unified transformation as a result of a moment-by-moment integration of an immense variety of physiological processes, finely organized into the hierarchy of the organic subsystems that constitute it.

The theory of dynamic systems would probably assert that a snapshot image of water molecules in a fluid would be insufficient to achieve a real understanding of the fluid, as the molecules form a complex temporal pattern. It would instead argue in favor of a film that displayed the patterned trajectory of the molecules over time. To this reasonable request, it must be added that biosystems do not really behave like the turbulence of fluids or of the atmosphere, but in the form of states in transition. Unlike that of dynamic systems of continuous evolution, life constitutes an intermittent and kinematical dynamics, thus, the information about its dynamic must include the identification of its particular states and the sequences of its patterns. We should therefore propose a theory of patterned processes that provides a language appropriate to describing both the structure and the activity of every biosystem, of every living organism.

## LIFE AS A PATTERNED PROCESS

Taking various concepts referring to biological or cultural evolution of certain forms and configurations (Harrison 1993), we can define patterned processes as spatio-temporal transitions which are essentially kinetic and particularly kinematical and which can be analyzed through particular configurations that evolve adaptively. These transitions occur between particular states in action and unfold in an ordered but unforeseeable manner. The patterned process of living organisms constitutes an integrated series of events connected to each other and that spread out in unison following a course recognizable as much for its structure as for its objective. The process includes manifestations as diverse as patterns of biochemical or physiological activity, patterns of motion that constitute behavior or cognitive patterns that include mental processes and ultimately consciousness itself.

Process and pattern are words that appear associated in very distinct disciplines when their objective is to identify and analyze the evolutionary dynamic of structures as varied as cultural objects, ecosystems, geological sediments, and biological species (Grande and Rieppel 1994, Hamilton 1967). This same approach could be used to understand vital processes, whose duration is marked by more physiological times. In effect, the processes of living organisms can be recognized collectively as stochastic transitions or particular patterns. Daniel Fisher closely approached the concept of a patterned process when he identified that certain events of hierarchically structured living beings, such as walking (which ranges from coordinated muscle activity to the microscopic functions of nervous and muscular physiology), can be described independently as patterns and as processes.

Vital processes are patterned for two critical reasons. They are patterned in the sense that they are defined chiefly by dynamic forms or configurations that we can identify in each case as *spatio-temporal patterns of activity*. These patterns are repetitive and recognizable at different levels of analysis, from the most elemental to the most complete in the definition of the process (Harrison 1993). They are also patterned because they are characterized by their spatio-temporality, in the morpho-functional sense that this concept should have and that compels both the theoretical and the experimental biologist to study discrete states as they develop over time. This means that patterned processes need to be described as the elements involved in a state of current activation and must also represent the dynamic of activity through the identification of its synchronized operations. In this way, patterned processes do not only consist in dynamic spatial configurations, but also in the deployment of these configurations or states in a peculiar and intricate behavior dependent on time. This spatio-temporal texture of activity is typical of patterned processes and can be defined by the combination, sequence, periodicity and quality of their formant states.

The term *combination* designates the simultaneous nature of the units in an amalgam of relationships between them. Through this amalgam the units of elements become synchronic (coexistent in time), form functional links with one another or unite in their purpose. *Sequence* refers to the chronological order in which events occur, i.e., to the ordered flow of configurations, units or states that have an appreciable result. Patterned processes possess a structure called kinematical when they involve the successive activation of operationally defined elements. In patterned processes, succession is defined by the probability of transitions occurring between them, a probability that is not totally a question of chance (spectral density $1/f^2$) nor strictly predictable (spectral power $1/f^0$); but stochastic, with an intermediate spectral density of 1/f which is found in DNA, in musical melody, in speech, and in human cognitive sequences. The semi-ordered series of consecutive or successive vital events provides evidence of the continuity, connection, consistence and progress of the states, steps or actions that make up a vital process. The word *progress* does not always imply development towards more complex states, as there is also a sequence of deterioration and death. *Periodicity* refers to the temporal fluctuation in which can be identified rhythms or intervals between cycles or units and which range from simple repetitions, such as walking steps, ultradian or circadian rhythms, to the more complicated repetitions of animal songs, human music and the prosody of language. Finally, the property and global attribute named *quality* refers here to the mode or manner in which the events occur. In the concept of *complexity* established by Brian Goodwing, living organisms express their nature and acquire meaning through the qualities peculiar to their forms.

Patterned processes are active and dynamic in the sense that they consist in movements and changes requiring kinetic energy. Their postulation as essential constituents of life highlights the replacement of the Newtonian and Cartesian notion of matter as static, which is largely incompatible with vital processes, with a notion of fluid energy belonging to any structure in action. Thus, a theory of patterned processes would be a kinetic theory as it would involve change, motion and operation, all of which explicitly conforms to the kinetic conception of modern science.

A theory of patterned processes is not bound in principle to a teleology, to a possible objective or finalist tendency of process, but it is bound, and very definitively, to its micro-structure. The goal or result of the process may well be inferred from the analysis of its units in sequence, in a way not very different from the deconstruction and deduction of the meaning of a clause using grammatical procedures. In this sense, the word *process* refers to an integrated series of connected events unfolding together in a coordinated manner, following a recognizable course or program (Rescher 1996) while the adjective *patterned* restricts the type of process to the different ways described above.

As a consequence of all these spatio-temporal and dynamic attributes, vital processes should be considered as patterned processes of a high order, which, due to their complex underlying structure and their resultant activity, involve and exhibit not only properties of information but also those other properties of life which to date still evade a precise definition.

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